Signal Processing Architectures for Ultra-Wideband Wide-Angle Synthetic Aperture Radar Applications

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Abstract

Approaches for parallel implementation of real-time image formation processing (IFP) for ultra-wideband wide-angle synthetic aperture radar (SAR) are discussed. Integration over wide-angles and ultra-wideband waveforms are typically required for applications with low operating frequencies as well as other important applications [1] [2] [3]. The wide integration angles and ultra-wideband (UWB) waveforms that are implemented for these type of state-of-the-art systems are intended to compensate for a loss in resolution in relation to systems that operate under standard systems parameters. State-of-the-art SAR image formation algorithms that address this ultra-wideband wide-angle problem includes time-domain backprojection-type algorithms and Fourier-based processing algorithms. An analysis of these algorithms in terms of computational gains as a function of HPC implementation parameters is presented. A sample set of simulation results are included that illustrate the trade-offs between image quality and computational efficiency. In addition, a discussion of approaches to implementing IFP post-processing algorithms that specifically address the real-time nature of this problem are presented.

Basic Approaches To SAR IFP
For Purposes Of This Investigation

- **Fourier-Based Approach With Mo-Comp to Scene Center [2]**
  - Traditionally Considered Computationally Efficient Frequency-Domain Technique for Purposes Real-Time Implementation [1] [2]
  - Image Quality Tends to Degrade with Distance from Scene Center

- **Time-Domain Backprojection [1]**
  - Even "Fast" Versions Traditionally Considered Too Computationally Intensive for Real-Time Airborne SAR IFP [3]
  - Generates High-Quality Imagery
  - Simulation Results Presented with Various Levels of Accuracy for Interpolator:

    nratio = 1 , 2 , 8 , 20 , 50 , 100 , 200

    where nratio is a "upsampling factor" for each time-domain radar pulse

- **Fourier-Based Approach with Post-Processing [1] [2]**
  - Also with Mo-Comp to Scene Center as with Approach 1 Above
  - Advanced Post-Processing Techniques Show Potential for Auto-Correction of Possible Sensor Calibration Errors Due to a Number of Physical Effects
  - This Block-by-Block Post-Processing is Performed at the Expense of Computational Efficiency

Six Notional Simulation Cases Defined For Comparative Investigation [1]

- case 1   Xc=1000   X0=100   Y0=120
- case 2   Xc=5000   X0=100   Y0=120
- case 3   Xc=6000   X0=240   Y0=222
- case 4   Xc=6000   X0=480   Y0=480
- case 5   Xc=6000   X0=600   Y0=600
- case 6   Xc=6000   X0=960   Y0=886

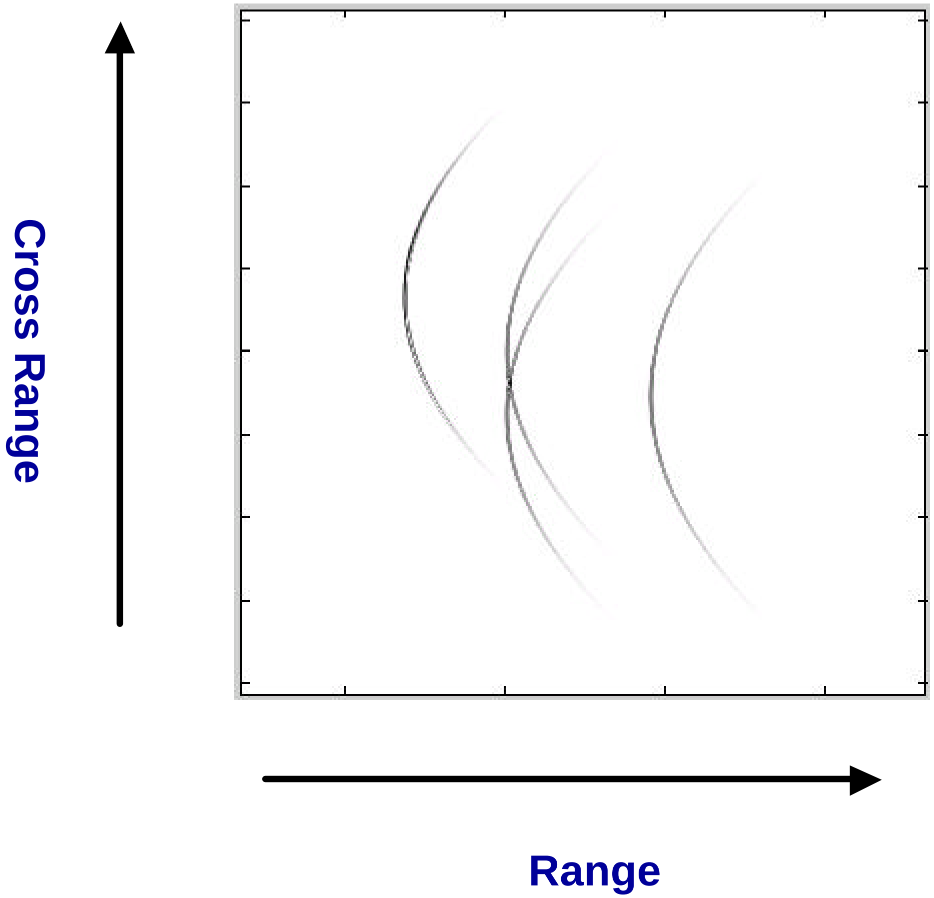
Where, for a given set of SAR system parameters, Xc is the Distance From the Platform to Scene Center in Meters, X0 is the Range Dimension of the Scene Size in Meters, and Y0 is the Cross-Range Dimension of the Scene Size in Meters

Case 1 (with total of all algorithms and all sets of algorithm parameters) executes in ~ 2.5 minutes on SOA single-processor PC with 512 Mbytes of RAM

Case 6 (with total all algorithms and all sets of algorithm parameters) executes in ~ 15 hours on SOA single-processor PC with 512 Mbytes of RAM

Sample Simulation Output

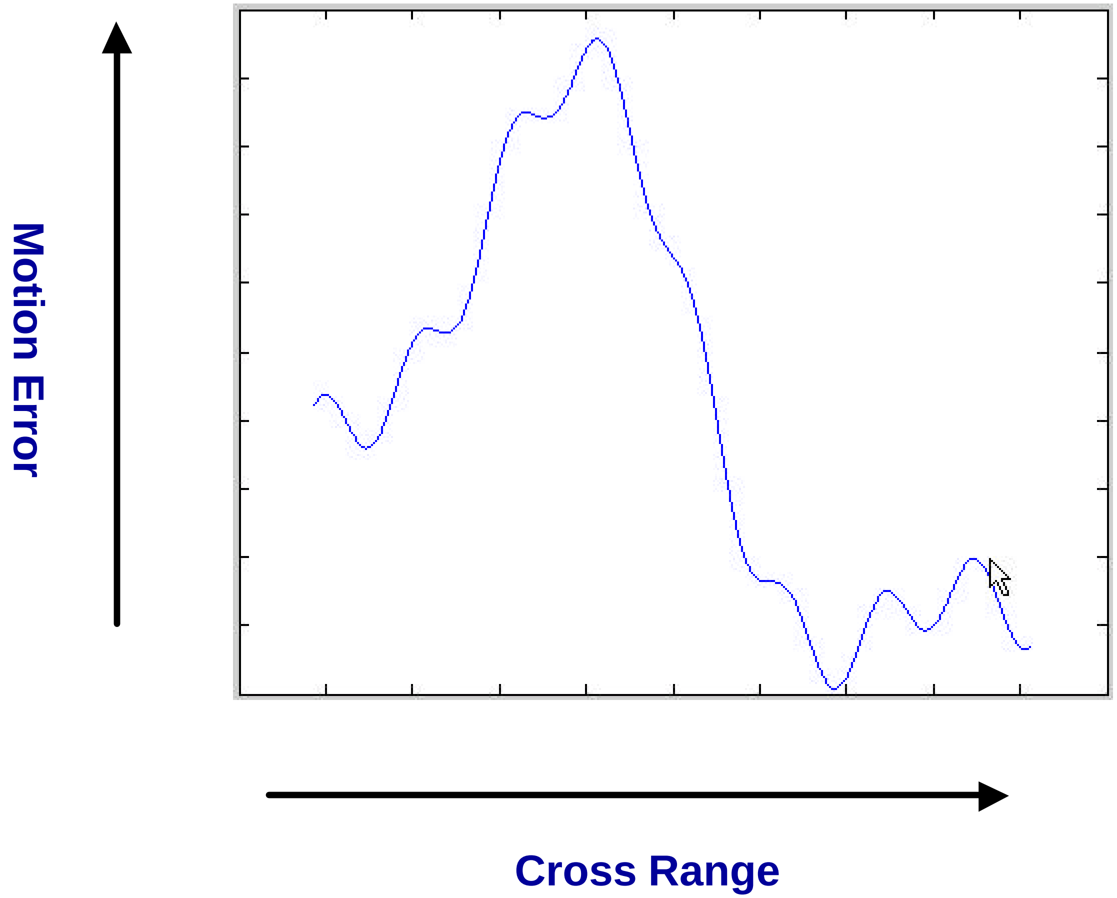
Simulated Wide-Angle SAR Signal



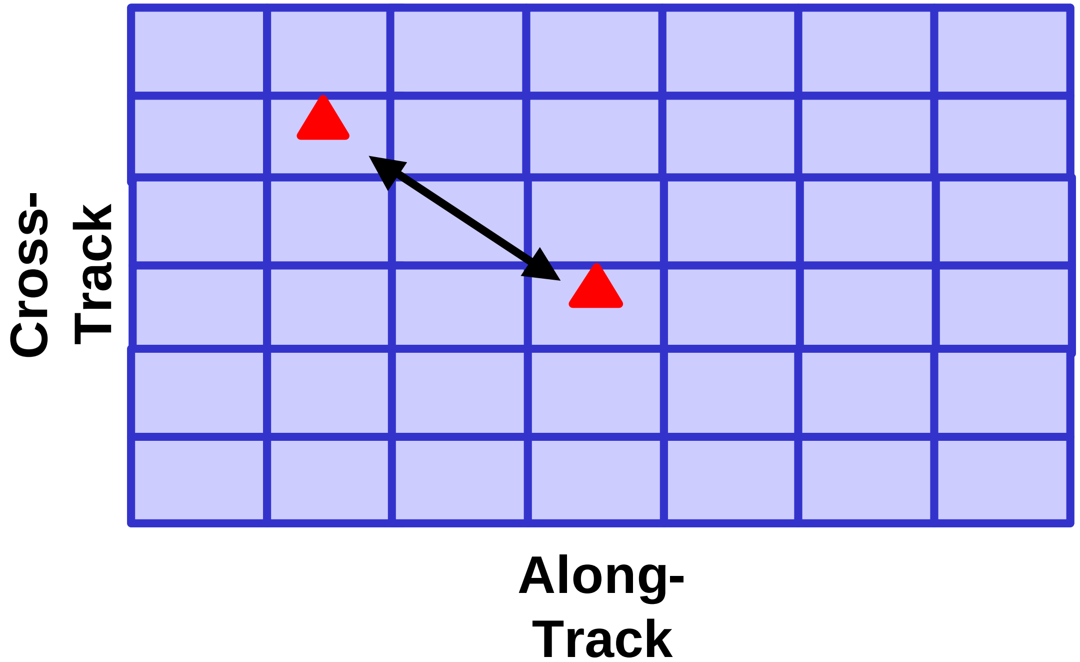
Sample Simulation Output

Model for Small Residual Error Signal

Small Residual Error Signal
Is Injected Into Signal On Previous Chart



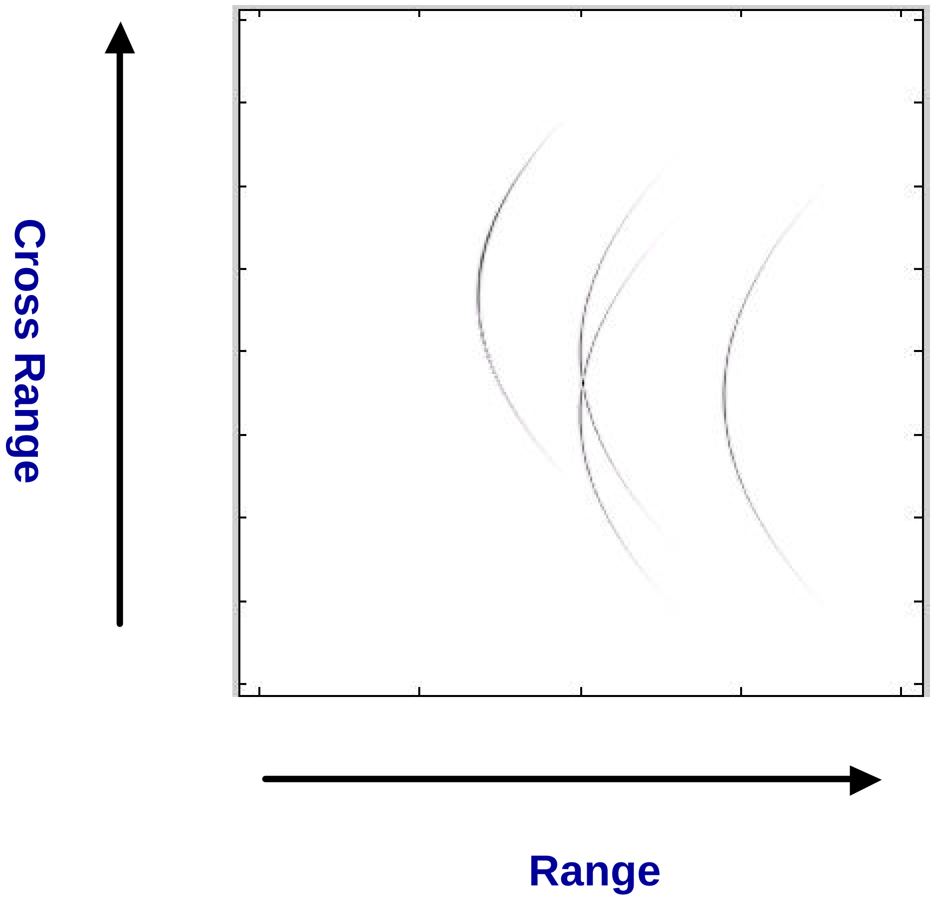
HPC Approach For Fourier-Based IFP and Auto-Cal Post-Processing



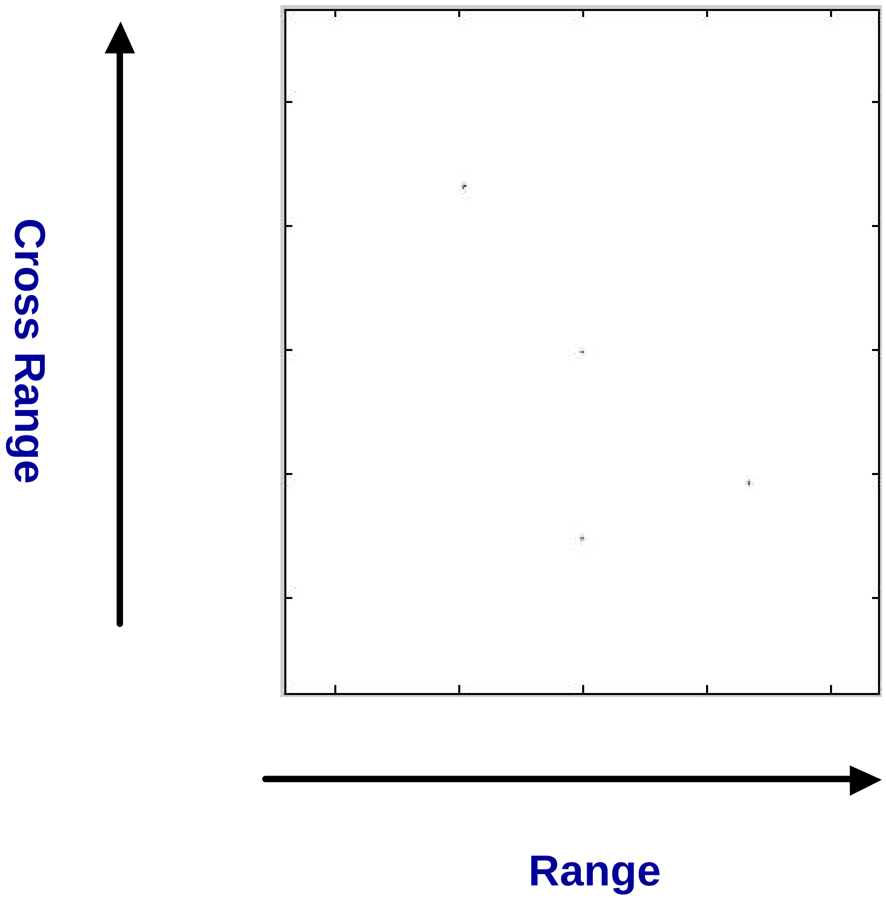
HPC Resource Management and Communications Paradigm Is Designed Such That Each Processor Is Assigned A Group of Localized Windows For Intensive Auto-Cal Post-Processing. The Computational Load Per Processor Is Determined By The Total Of Localized Windows That Are Selected And The Number Of Processors. This Block-by-Block Auto-Cal Post-Processing Is Intended To "Re-Calibrate" Localized Regions Of The Image For Mo-Comp Errors During The Fourier-Based IFP Which Performs Mo-Comp To Scene Center and To "Re-Calibrate" Localized Regions Due to Residual "Time Dependent" Sensor Fluctuations

Sample Simulation Output

After Matched Filtering in Range Dimension

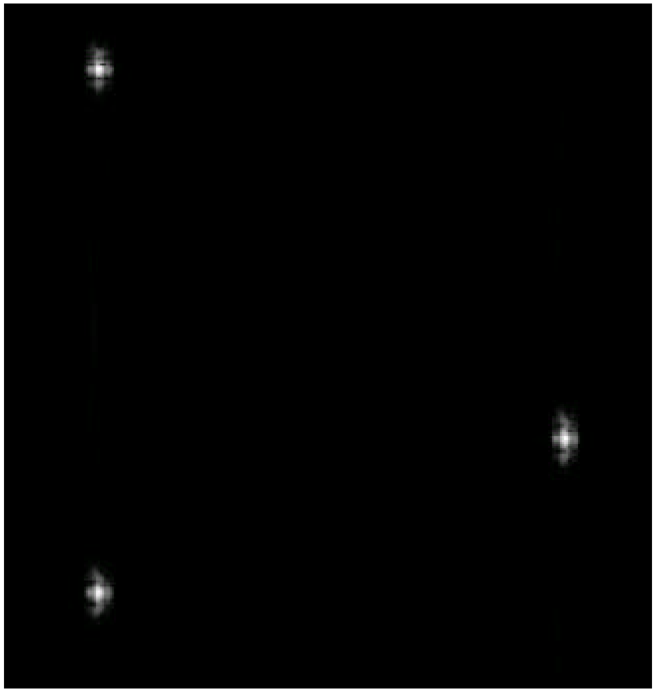


Sample Simulation Output

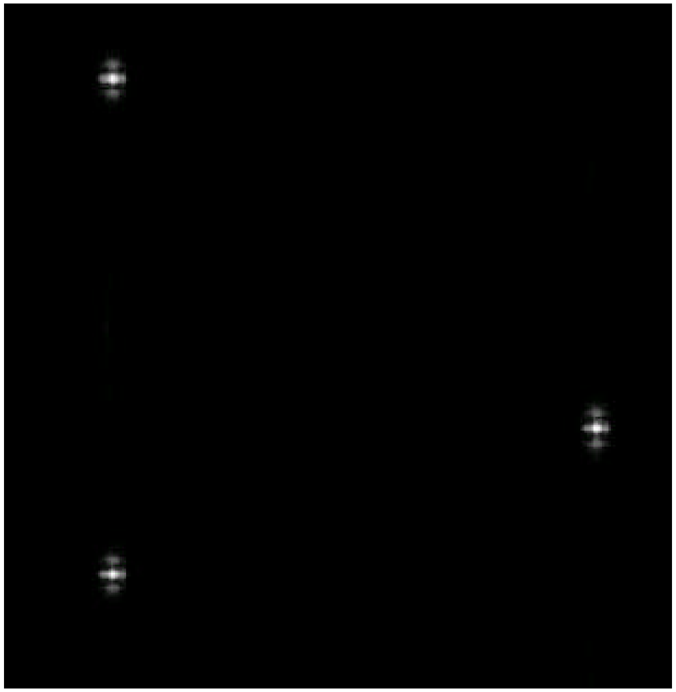


After Matched Filtering in Cross Range and Interpolation To Compensate for Range Migration and Range Curvature Due To Wide-Angle IFP Process for UWB Radar Application

Sample Simulation Output

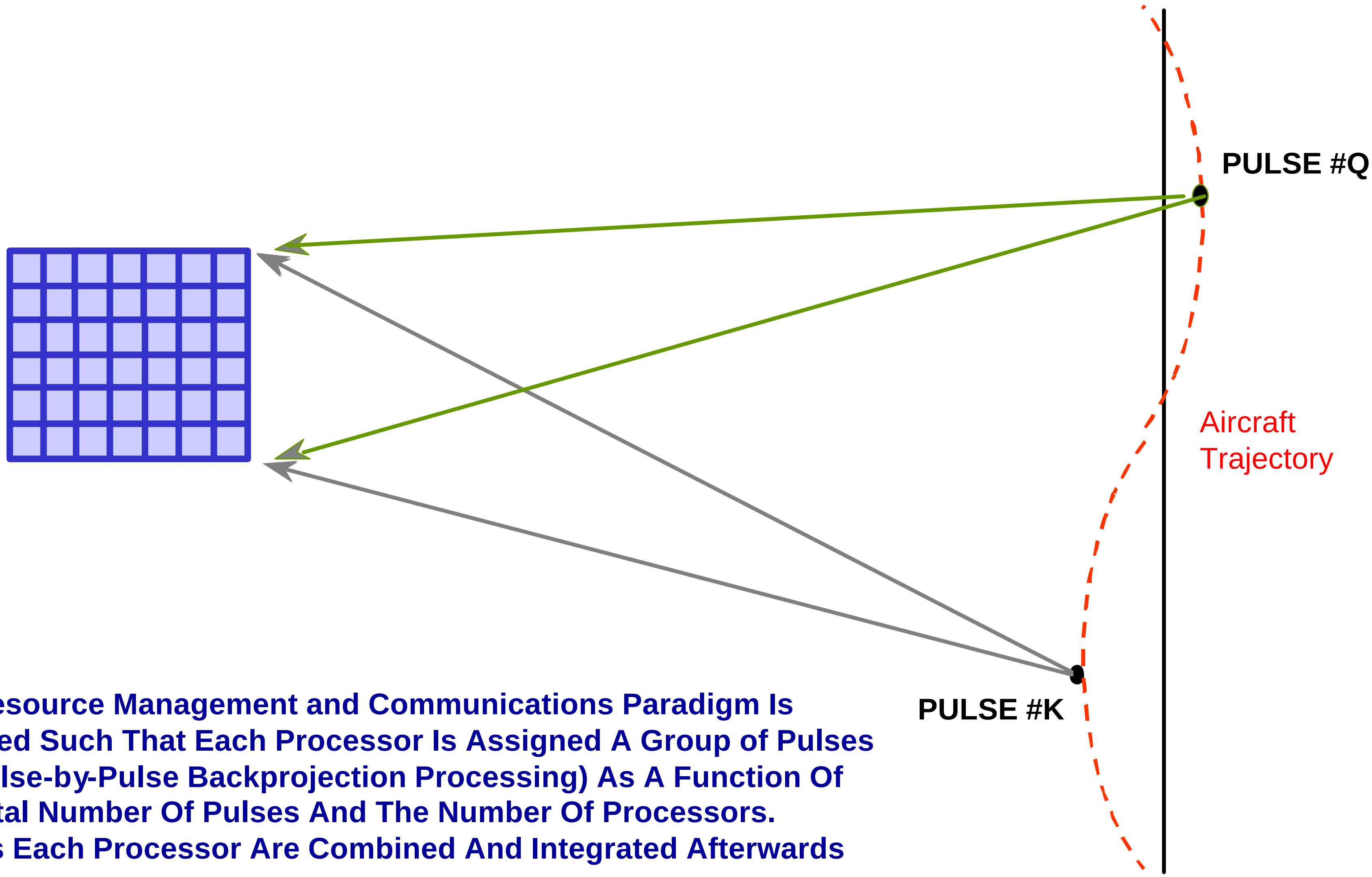


W/O Auto-Cal Post-Processing



With Auto-Cal Post-Processing

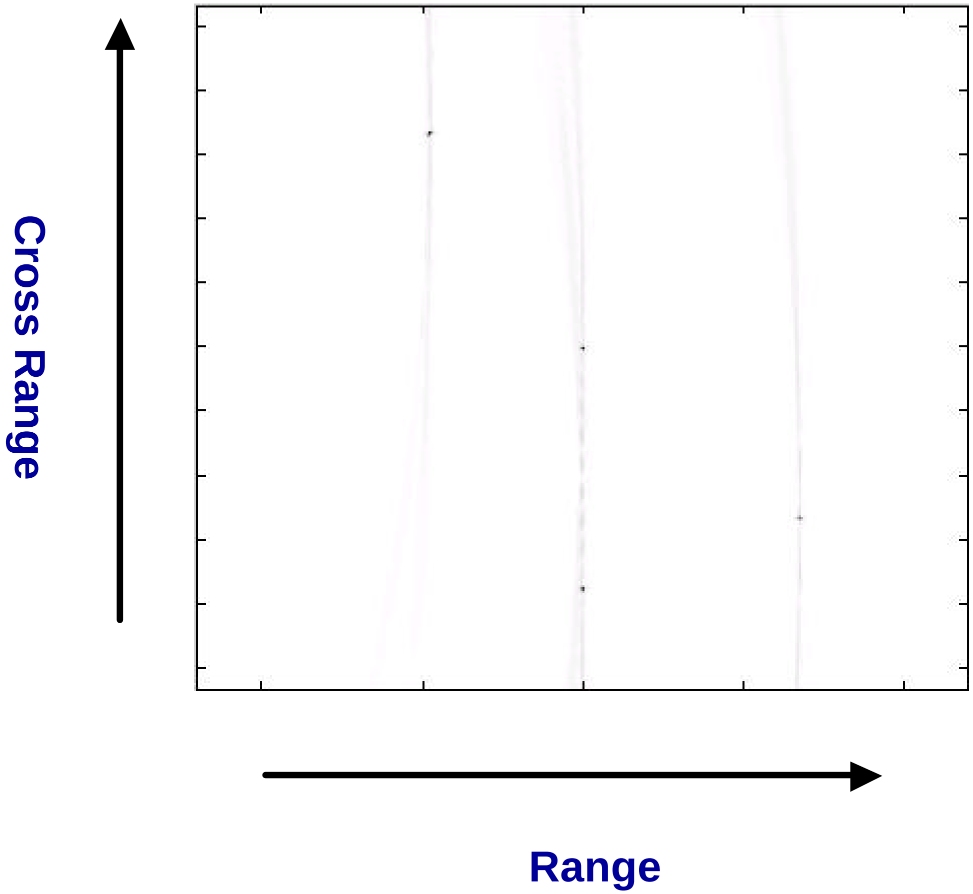
HPC Approach For Backprojection Implementation



HPC Resource Management and Communications Paradigm Is Designed Such That Each Processor Is Assigned A Group of Pulses (For Pulse-by-Pulse Backprojection Processing) As A Function Of The Total Number Of Pulses And The Number Of Processors. Results Each Processor Are Combined And Integrated Afterwards

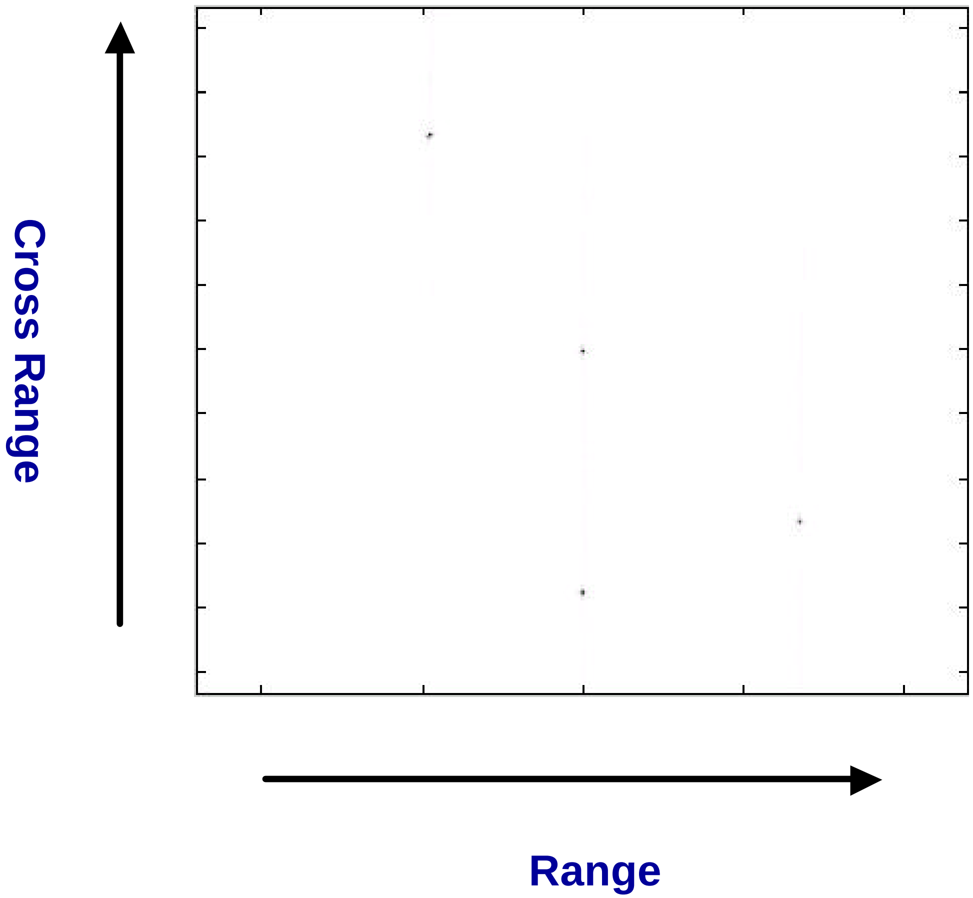
Sample Simulation Output

n_ratio = 1

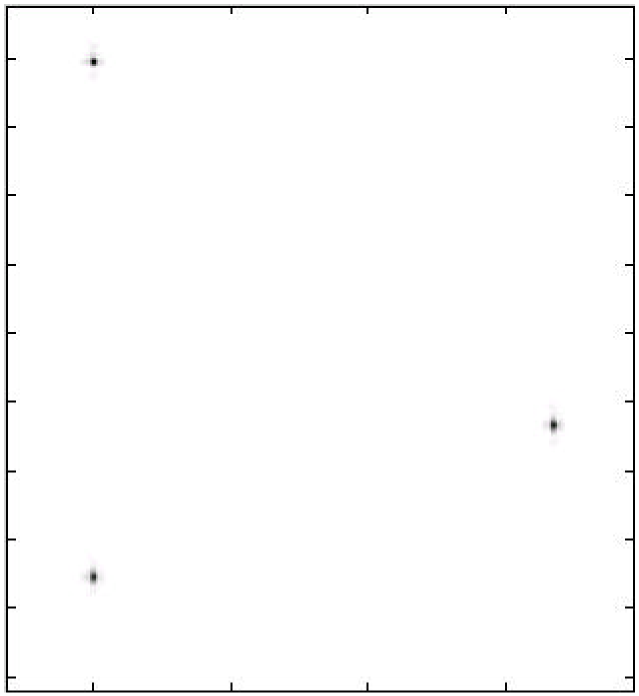


Sample Simulation Output

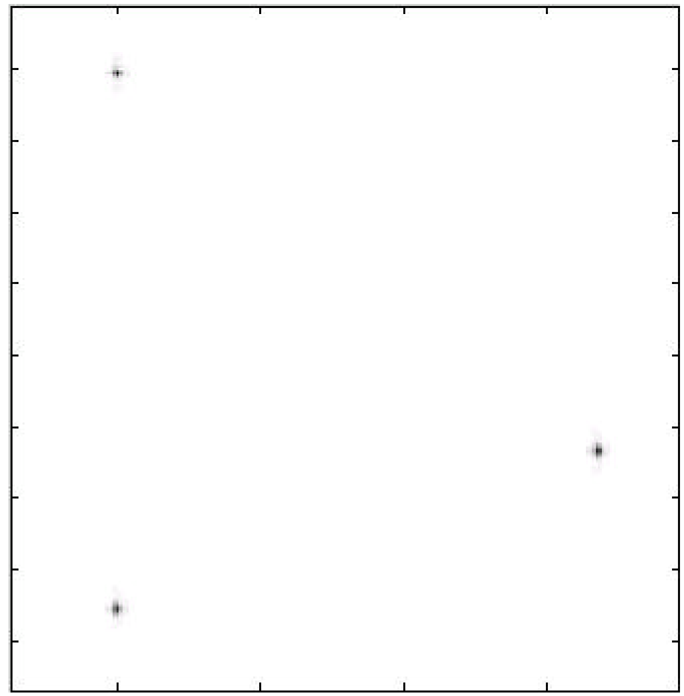
n_ratio = 2



Sample Simulation Output

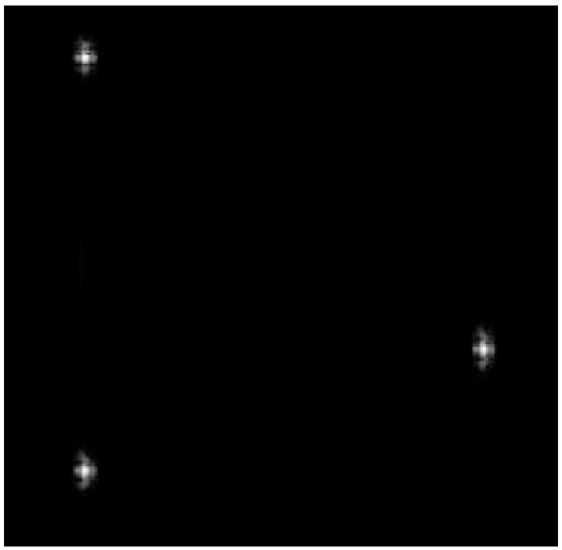


n_ratio = 20

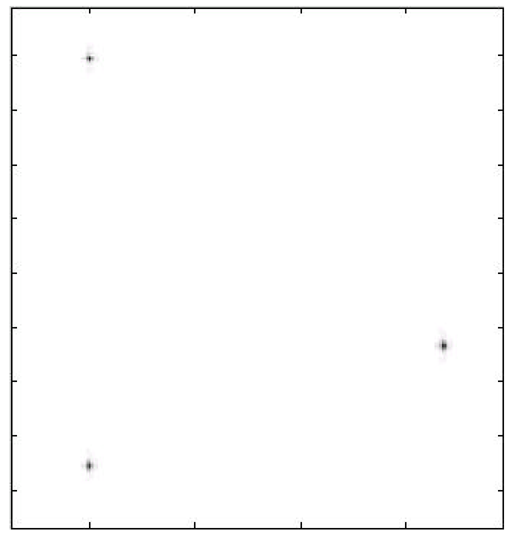


n_ratio = 200

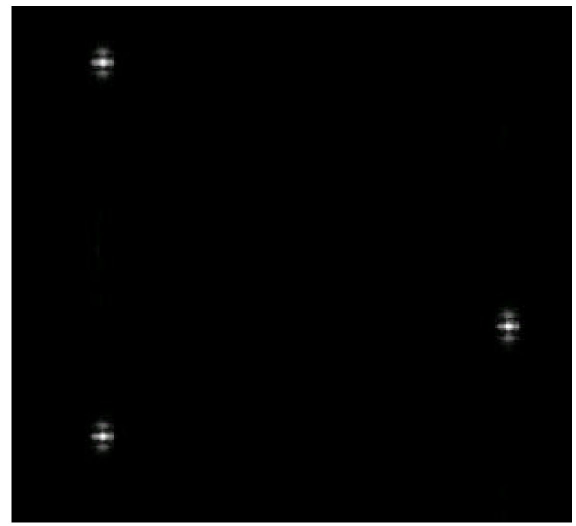
Sample Simulation Output



W/O Auto-Cal



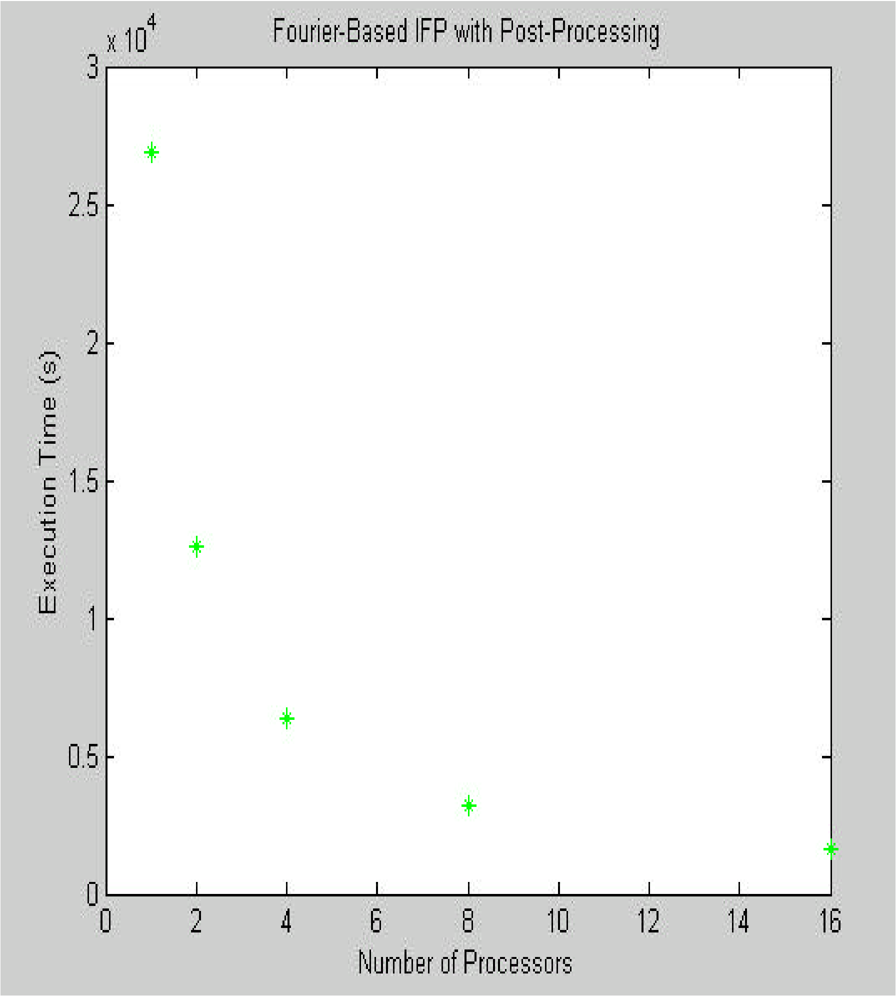
n_ratio = 200

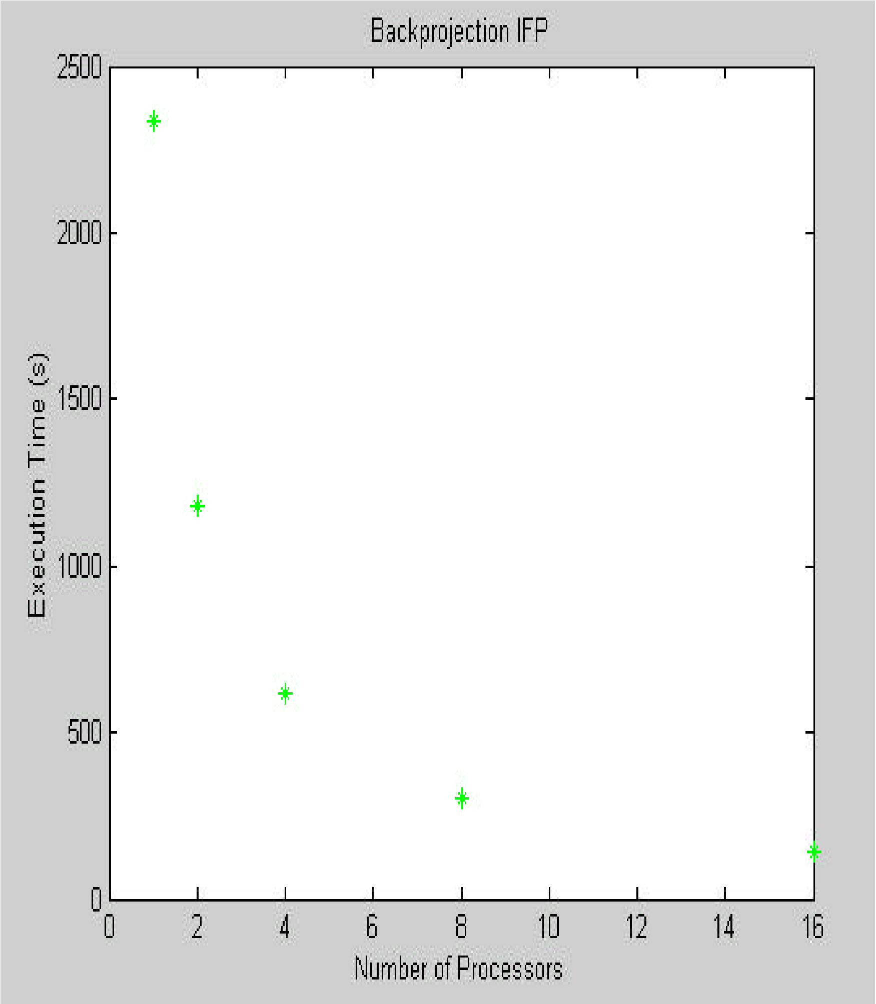


With Auto-Cal

HPC Analysis

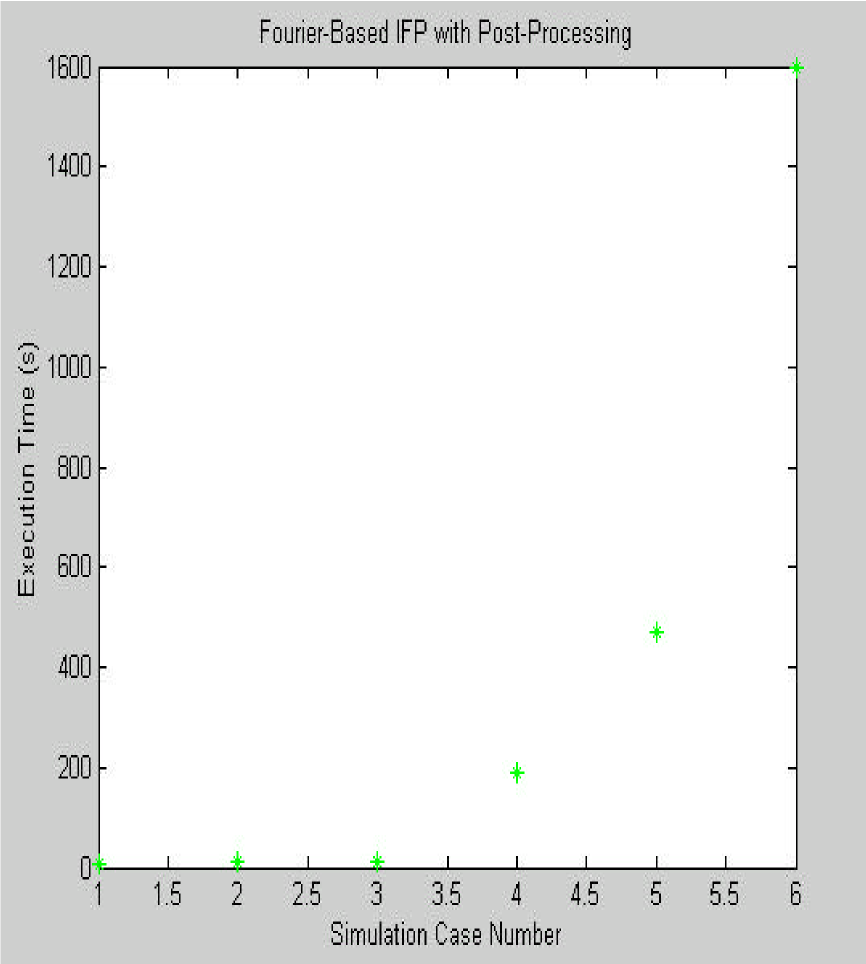
Case 6

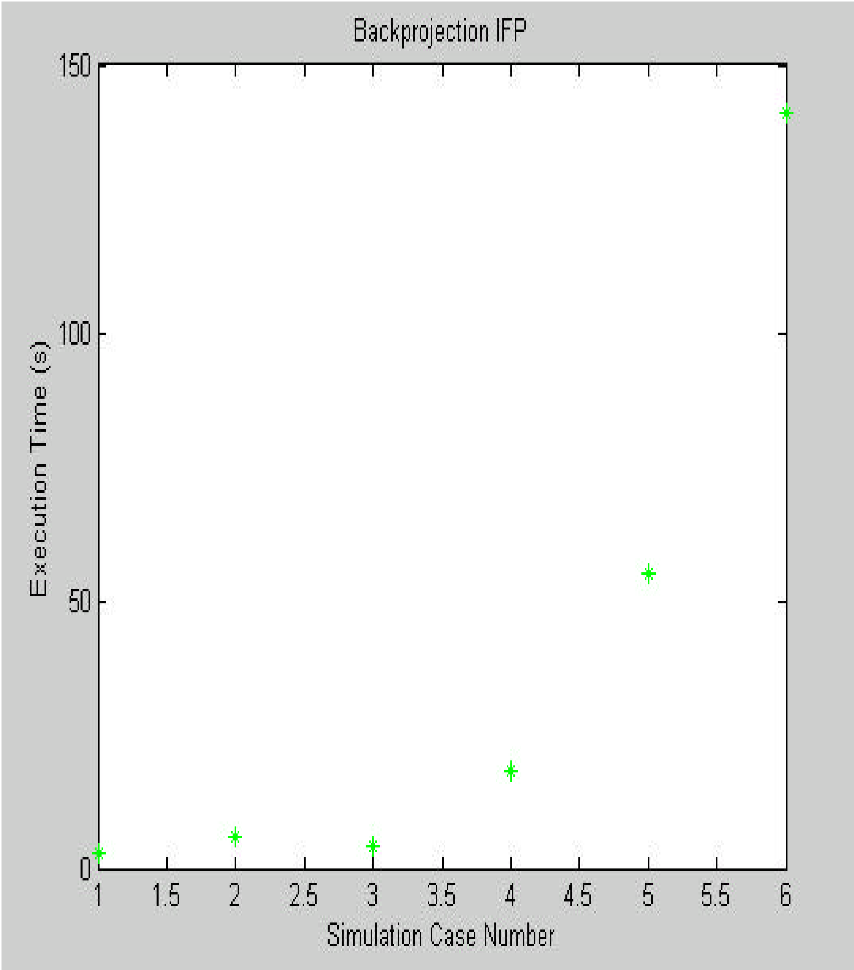




HPC Analysis

16 Processors





Summary

- **Parallel Implementations for Three Approaches To IFP for Real-Time UWB SAR Were Developed and Investigated**
- **Preliminary Results Indicate That Backprojection Implementation is Computationally Efficient and Generates Good Image Quality for Many Real-Time UWB SAR Applications of Interest**
- **Preliminary Results Indicate That Low-Order Interpolator for Backprojection Implementation May Generate Acceptable Image Quality for Many Real-Time UWB SAR Applications of Interest**
- **Preliminary Results Indicate That Fourier-Based IFP Processing With Intensive Auto-Cal Post-Processing Can Be Developed and Implemented To Compensate For Defocusing Errors On Systems and Scenarios That Are Associated With Significant Amounts of Residual Errors Due To Time-Dependent Sensor Fluctuations and Mo-Comp Sensor Errors**

References

[1] Mehrdad Soumekh, *Synthetic Aperture Radar Signal Processing with MATLAB Algorithms,* Wiley Interscience, 1999.

[2] W. G. Carrara, et al. *Spotlight Synthetic Aperture Radar Signal Processing Algorithms.* Artech House, 1995.

[3] A. F. Yegulalp, "Fast Backprojection Algorithm for Synthetic Aperture Radar," Proceedings of the IEEE National Radar Conference, 1999, pp. 60 – 65.